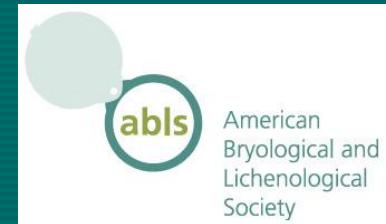




## Lichen Bioindication of Air Quality Symposium



# The Evolving Role of Lichens in Air Quality Protection on Public Lands



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# Introduction

- Federal land managers (FLMs) have Clean Air Act-assigned responsibilities to protect air quality in Class 1 Wilderness, national parks, and wildlife refuges.
- FLMs have been using lichens for nearly 3 decades to understand air pollution.
- Lichen monitoring is evolving in that we are using lichens to track more pollutants, using more sophisticated community and analytical chemistry techniques, and increasingly, integrating lichen data with other monitoring and information sources.
- I present some examples from the western US illustrating current uses of lichen data to understand, abate, or prevent air pollution.

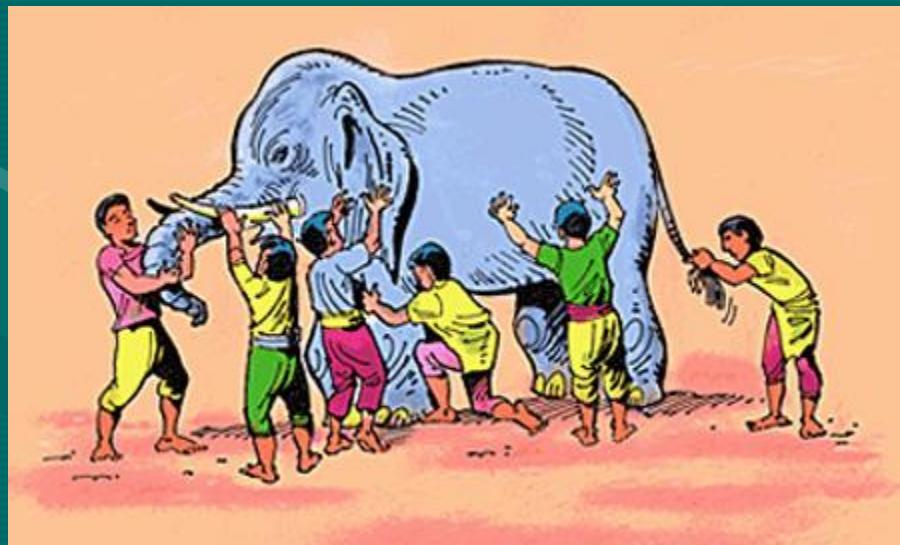


# General Approach

- Know the laws, regulations, mandates, agency responsibilities pertinent to the study area
- Work with partners
- Obtain multiple lines of scientifically credible information to better understand pollutants, their sources, and their effects.
- Inform supervisors of results, recommendations, and obtain their backing
- Raise public awareness by making results available to the media, answer questions, and attend public meetings
- Focus time and resource expenditures where effecting change is possible, team up with partners, and involve stakeholders.

# Avoiding the 'Blind Men and Elephant' Scenario

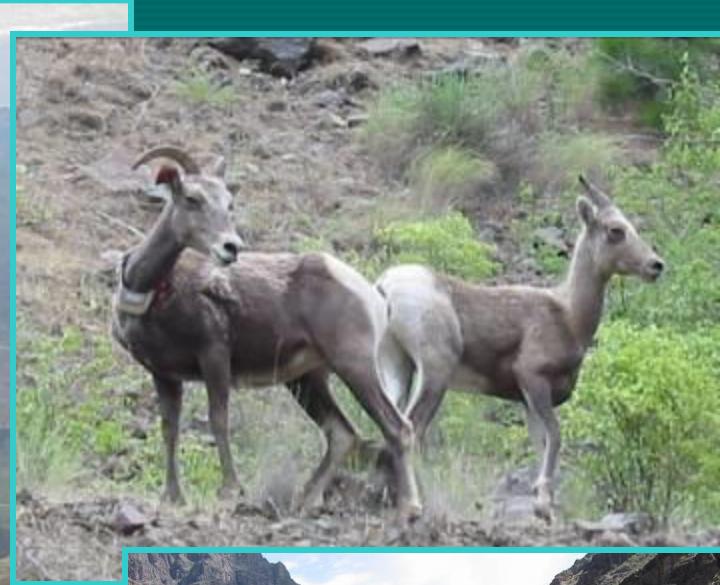
Like the blind men, each describing the whole elephant from a single part, what we think is going on usually depends on what we measure. We are increasingly recognizing that the most accurate understanding comes from interpreting multiple information sources.



*O how they cling and wrangle, some  
who claim  
For preacher and monk the  
honored name!  
For, quarreling, each to his view  
they cling.  
Such folk see only one side of a  
thing.*

*Siddhārtha Gautama* ~528 BC

# Example 1. Hells Canyon Wilderness and National Recreation Area



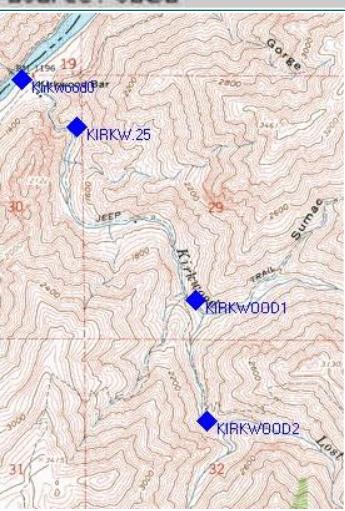


*Forest Service archeologist Bruce Womak recreates rock art using local clays as pigments in Hells Canyon National Recreation Area.*

# Example 1. Hells Canyon Wilderness and National Recreation Area



- We were like one of the blind men because we had memorized the NADP map—wet deposition at HCRNA is among the lowest in the nation, so we almost laughed them off.
- Talked into a one-day study, we made grab samples of *Xanthoparmelia* for %N and noticed the extensive cover of *Xanthoria* on hackberry along the banks of the Snake River.
- Suddenly we were like a second blind man because now we thought nitrogen deposition must be extremely high!



- 4 tributaries, 3 primary and 1 secondary to the Snake R.
- 4 plots per tributary, 3 km transects
- 16 plots total
- Plots restricted to net-leaf hackberry-bluestem bunchgrass plant community.

# Example 1. Hells Canyon

One week  
lichen  
study

Measured:

- Nitrophilous lichen cover,
- Lichen N & S content,
- Bark pH,
- Lichen community composition

Collected habitat data.



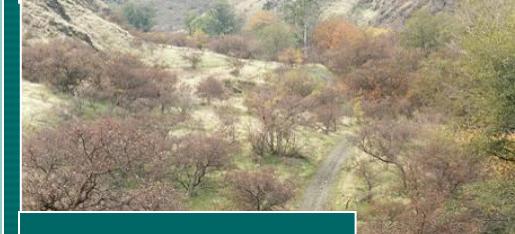
Lichen %N



Lichen cover



Bark pH



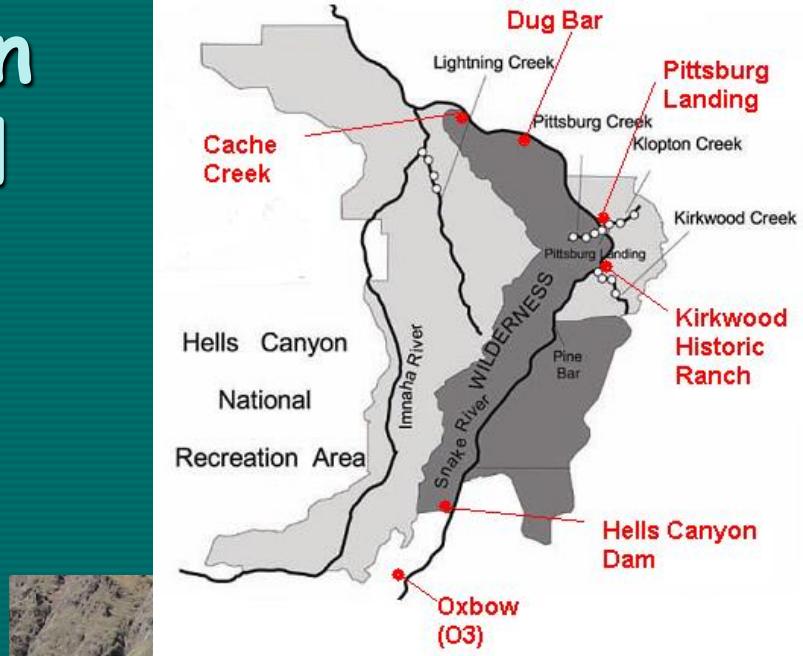
Lichen survey

# Example 1. Hells Canyon Wilderness and National Recreation Area

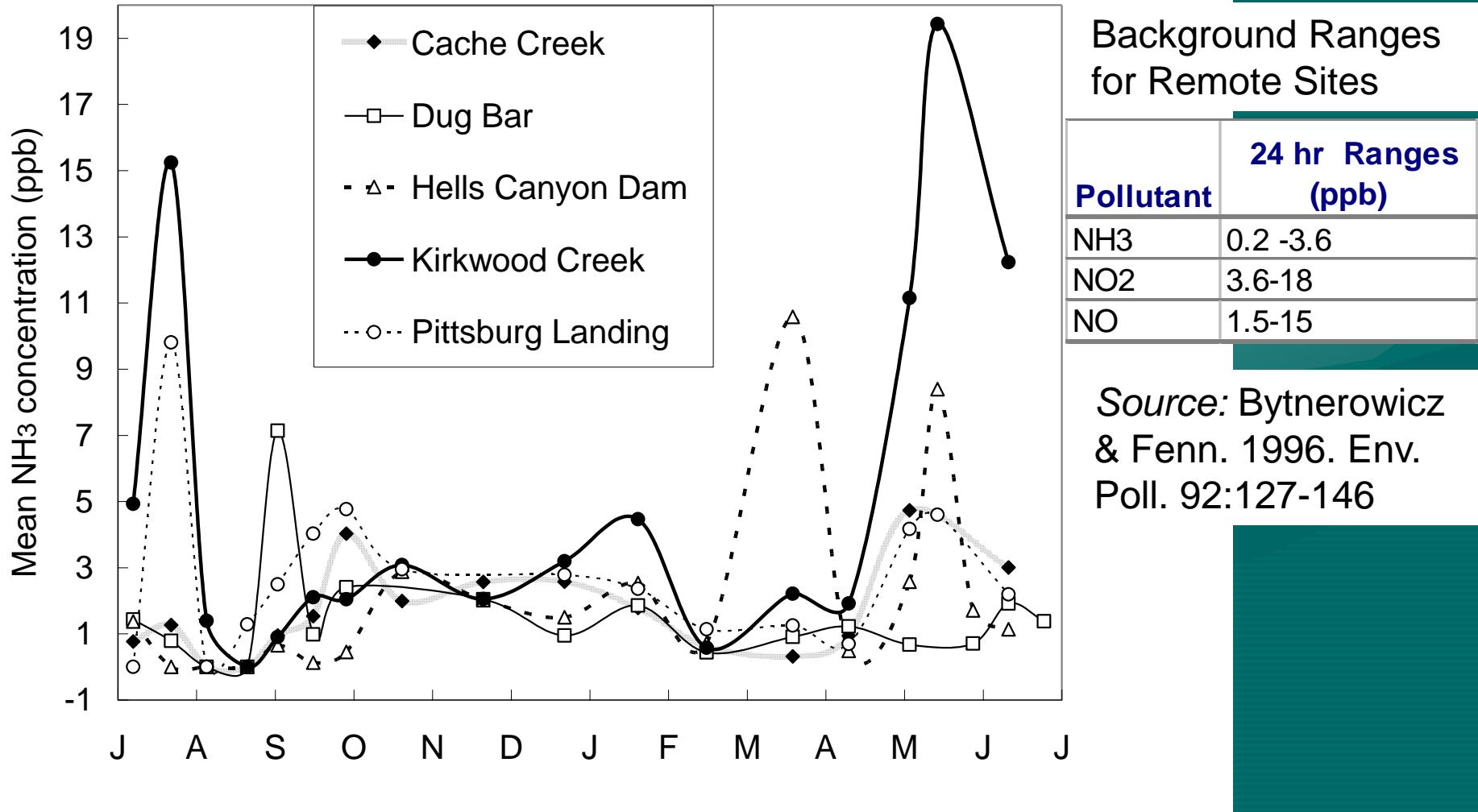
- The lichen study showed that highest % N in *Xanthoparmelia*, highest cover of *Xanthoria*, and the most nitrophyte-dominated, species-poor lichen communities occurred within 0.5 km of the Snake River
- At other sites lichen %N was lower but still significantly higher than other remote NW sites and still dominated by nitrophytic lichens, though cover was lower.
- Bark pH pointed toward an alkaline nitrogen source, i.e. ammonia as opposed to a neutral (ammonium nitrate) or acidic (nitric acid) source.

# Example 1. Hells Canyon Wilderness and National Recreation Area

- **New questions:** Is the river a source of ammonia? What other pollutants are present? Is there an overlaying regional contribution? Are pollution levels high enough to threaten other natural resources or to damage rock art?
- **Passive sampling** at 5 stations along the Snake R in Hells Canyon. Quantified biweekly-monthly mean ambient NH<sub>3</sub>, NO<sub>x</sub>, NO<sub>2</sub>, SO<sub>2</sub>, H<sub>2</sub>S.
- **Continuous ozone** measurements in spring and summer at the IMPROVE site in Oxbow Village, OR (HECA).
- Daily NH<sub>4</sub>NO<sub>3</sub> and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> concentrations in fine particulates from HECA for study period.
- Air mass back trajectories for HECA.

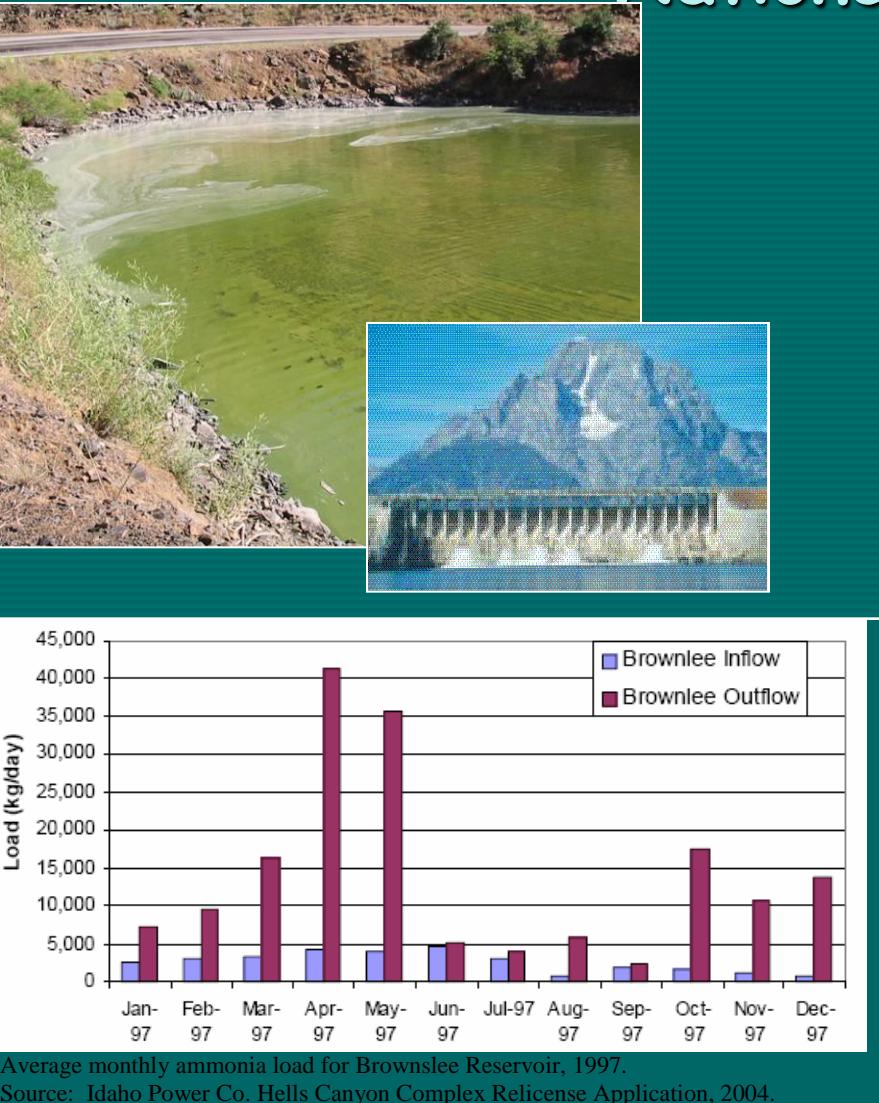


# Example 1. Hells Canyon Wilderness and National Recreation Area



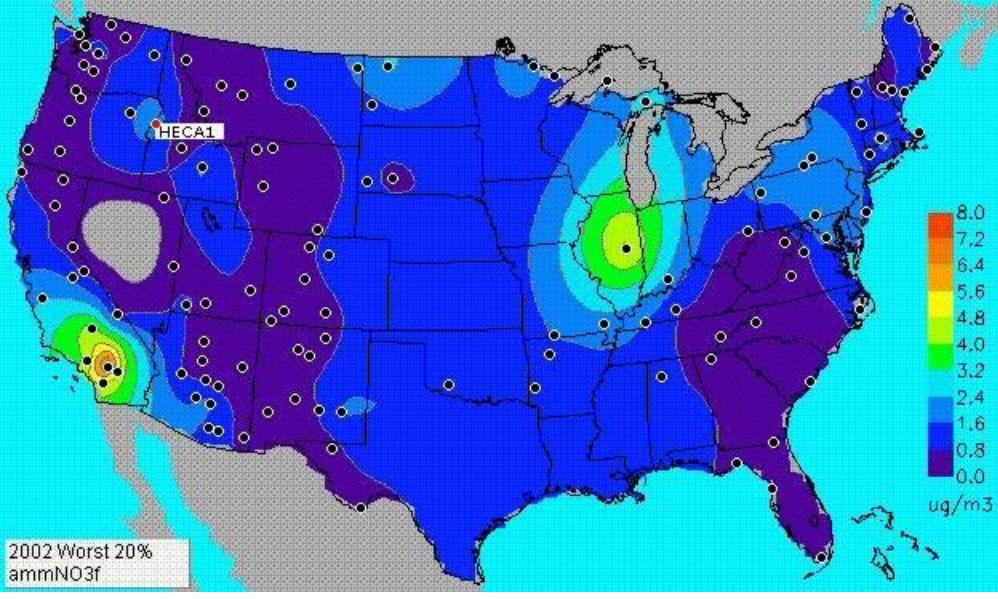
Ozone,  $\text{NO}_x$ ,  $\text{H}_2\text{S}$ ,  $\text{SO}_2$  were low all year but there were episodes of very high  $\text{NH}_3$  in spring and late summer.

# Example 1. Hells Canyon Wilderness and National Recreation Area

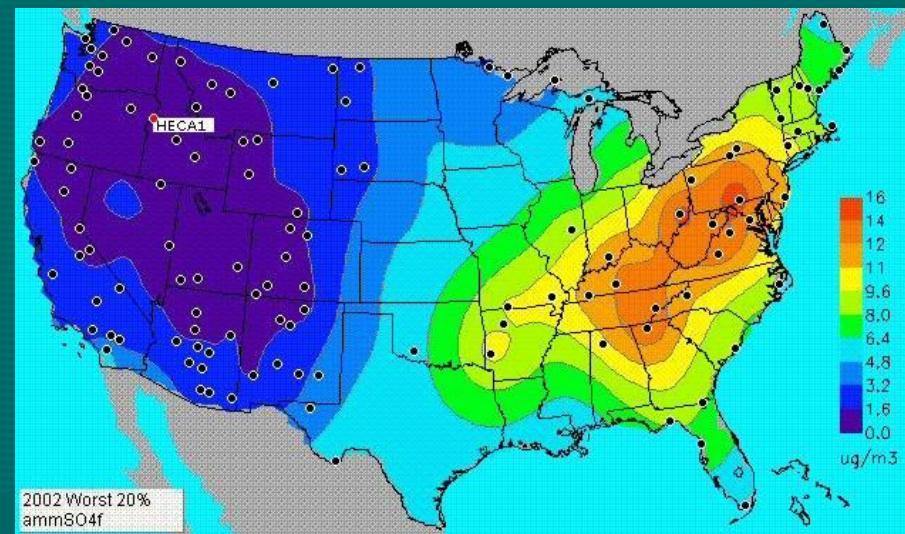
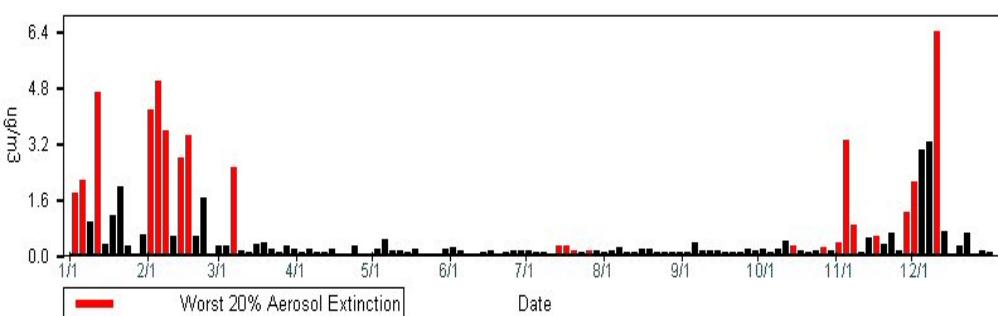


- Agriculture in Idaho is a major source of N, P in the Snake R
- Eutrophication causes extensive growth of algae which sink to deep, anoxic waters behind Snake R dams; nitrification ceases and  $\text{NH}_4^+$  accumulates.
- Rapid algal growth consumes  $\text{CO}_2$ , raising river pH to 9.
- Water released from the bottom of Hells Canyon Dam is high in  $\text{NH}_4^+$ . The 1997 net release was 4.3 million kg  $\text{NH}_4^+$ . High pH favors conversion to  $\text{NH}_3$  and volatilization.
- $\text{NH}_3$  deposits rapidly to vegetation surfaces, especially moist microsites closest to the river

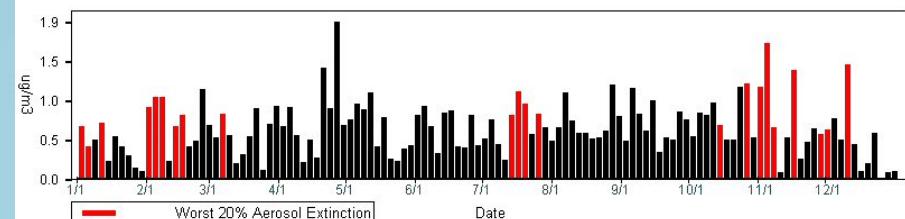
# Example 1. Hells Canyon Wilderness and National Recreation Area



HECA1 2002 ammNO<sub>3</sub>f



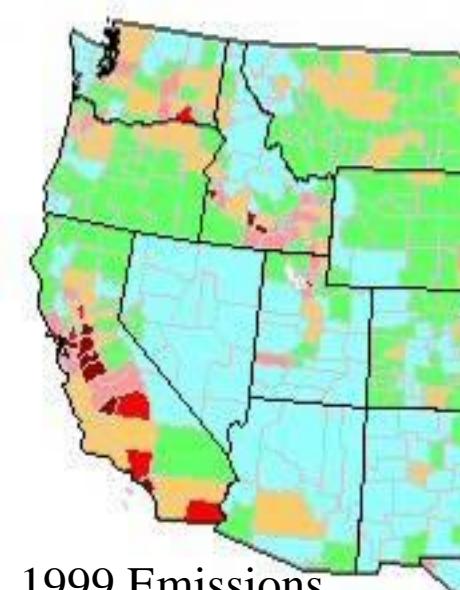
HECA1 2002 ammSO<sub>4</sub>f



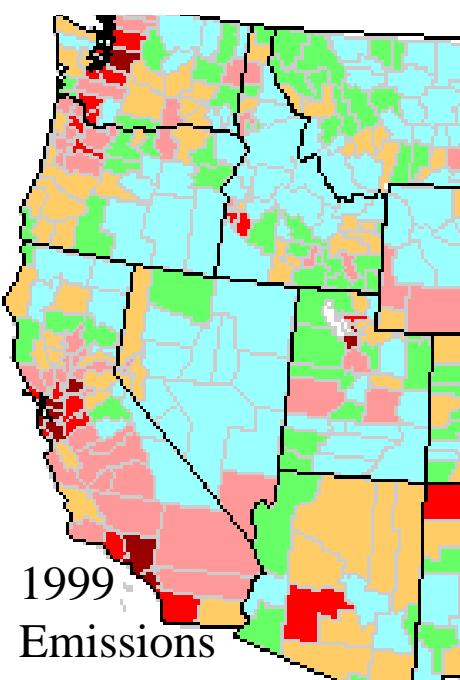
- HECA ( $\text{NH}_4\text{NO}_3$ ) was low all year and similar to other western sites.

- $\text{NH}_4\text{NO}_3$  concentrations in fine particulates at HECA are higher than other western US sites (excluding southern CA) on the 20% of days when visibility is most impaired.
- The highest  $\text{NH}_4\text{NO}_3$  days at HECA occur in winter.

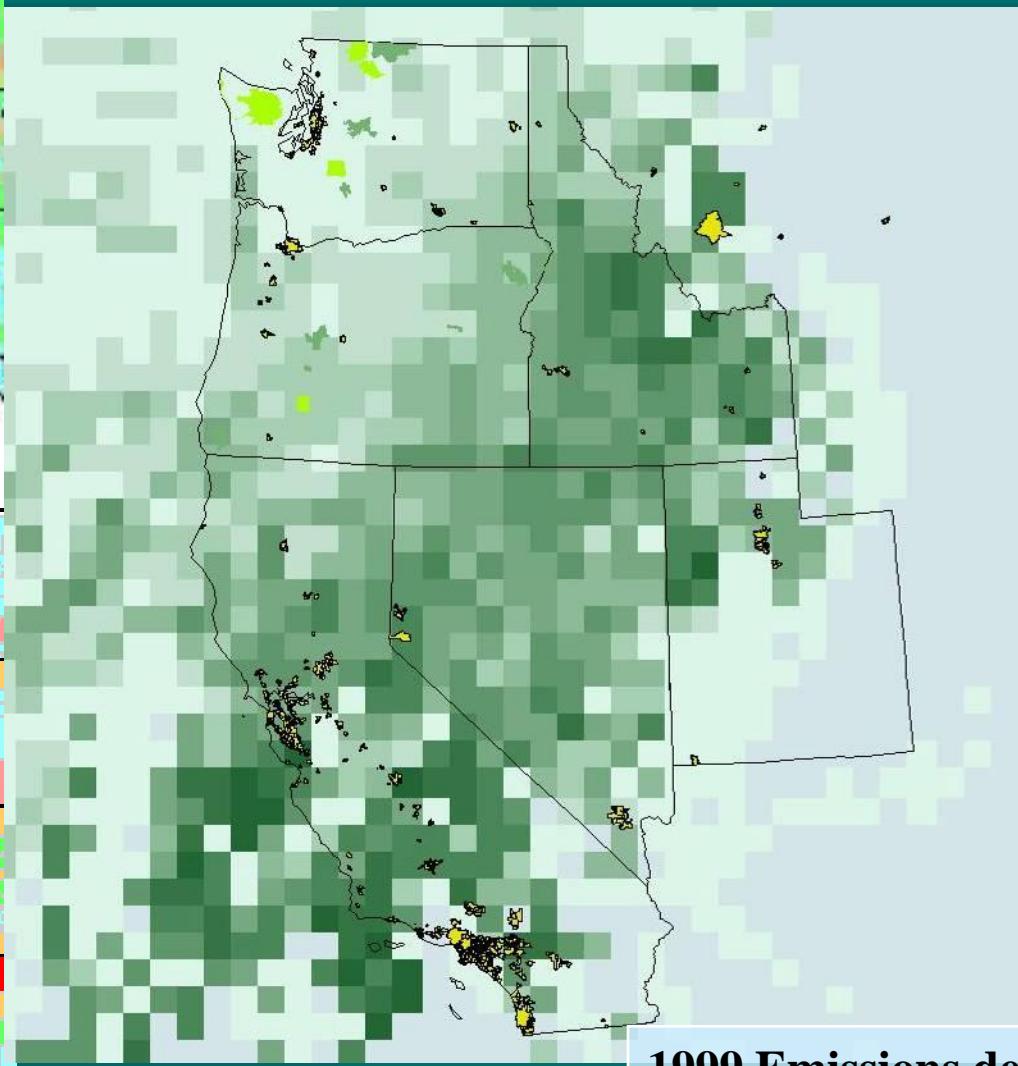
# Example 1. Hells Canyon Wilderness and National Recreation Area



1999 Emissions  
Density NH<sub>3</sub>



1999  
Emissions  
Density NOx



1999 Emissions densities vs. 96 hr  
back trajectory conditional  
probabilities on high NH<sub>4</sub>NO<sub>3</sub> days

Regional sources contribute to high background N:

- Snake River Basin
- San Francisco Bay Area
- Southern California

# Example 1. Hells Canyon Wilderness and National Recreation Area

- Results used so far to:
  - Obtain funding for rock art monitoring from Idaho Power via the FERC process
  - Inform public; featured in Sunday lead article in the state newspaper, The Oregonian
  - Publish 2 scientific articles, presentations
- Next steps are to:
  - Seek improvement of water quality in the Hells Canyon reach by requesting state regulators to enforce the TMDL standards
  - Build support for reduction of regional fine particulates using the regional haze rule.
  - Support on-going efforts to improve regulation of large-scale agriculture and CAFOs.

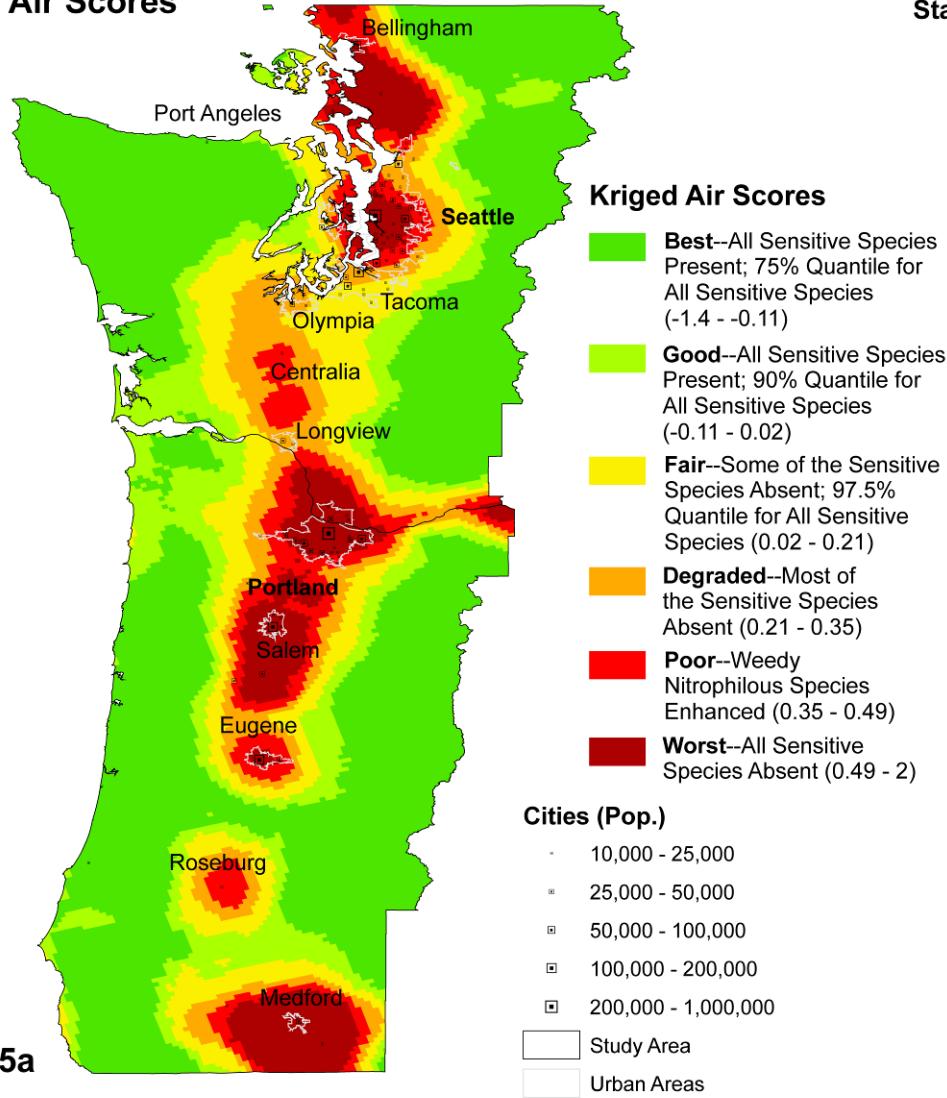
## *Example 2. Columbia River Gorge National Scenic Area*



*Vista of the Columbia Gorge from Washington facing Mt. Hood in Oregon*

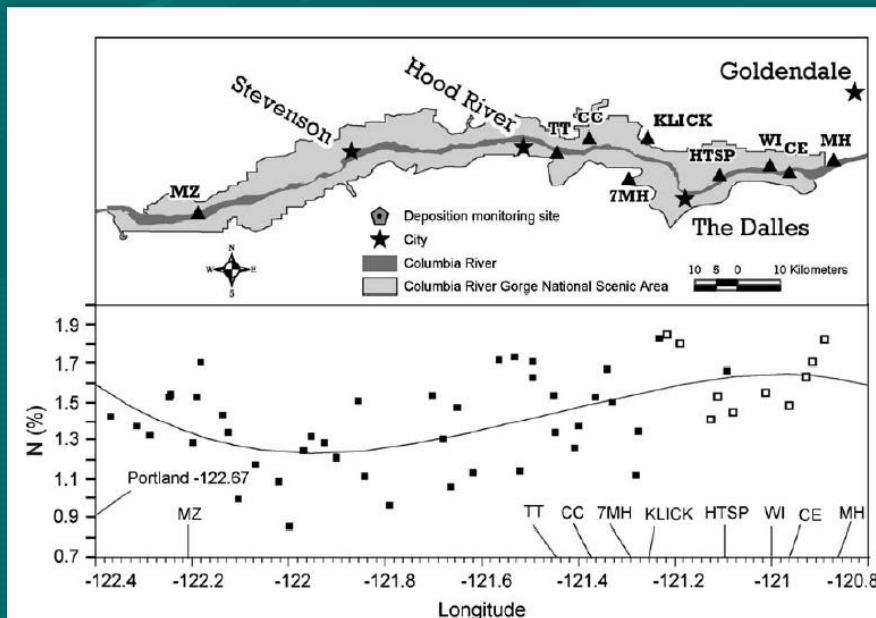
# Example 2. Columbia River Gorge National Scenic Area

Air Scores

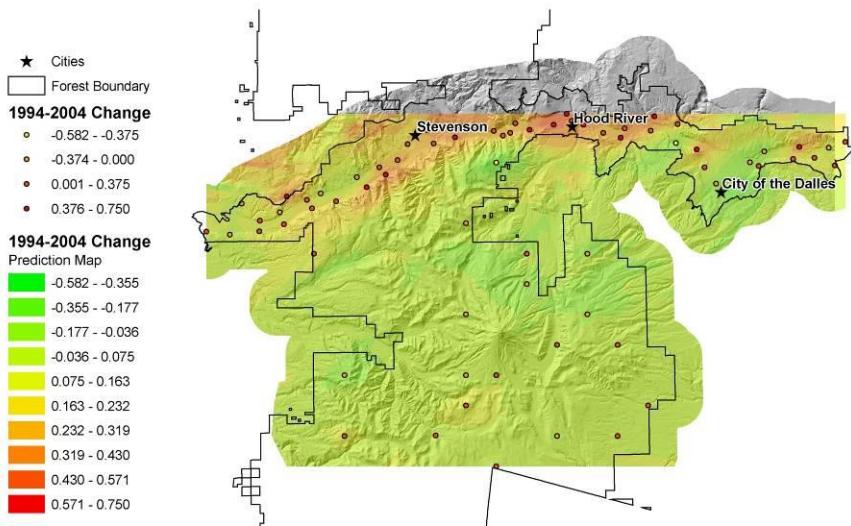
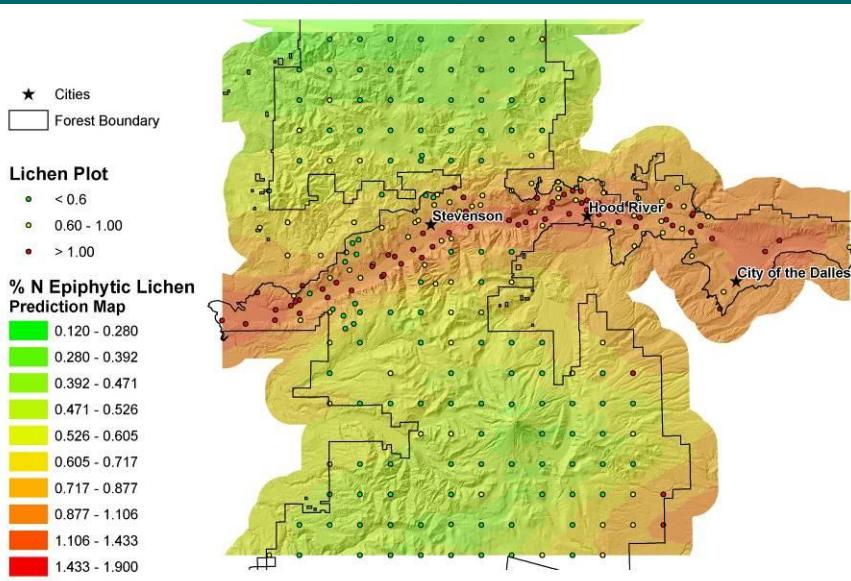


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Lichen data show N deposition and community patterns in the CRG and remote sites.



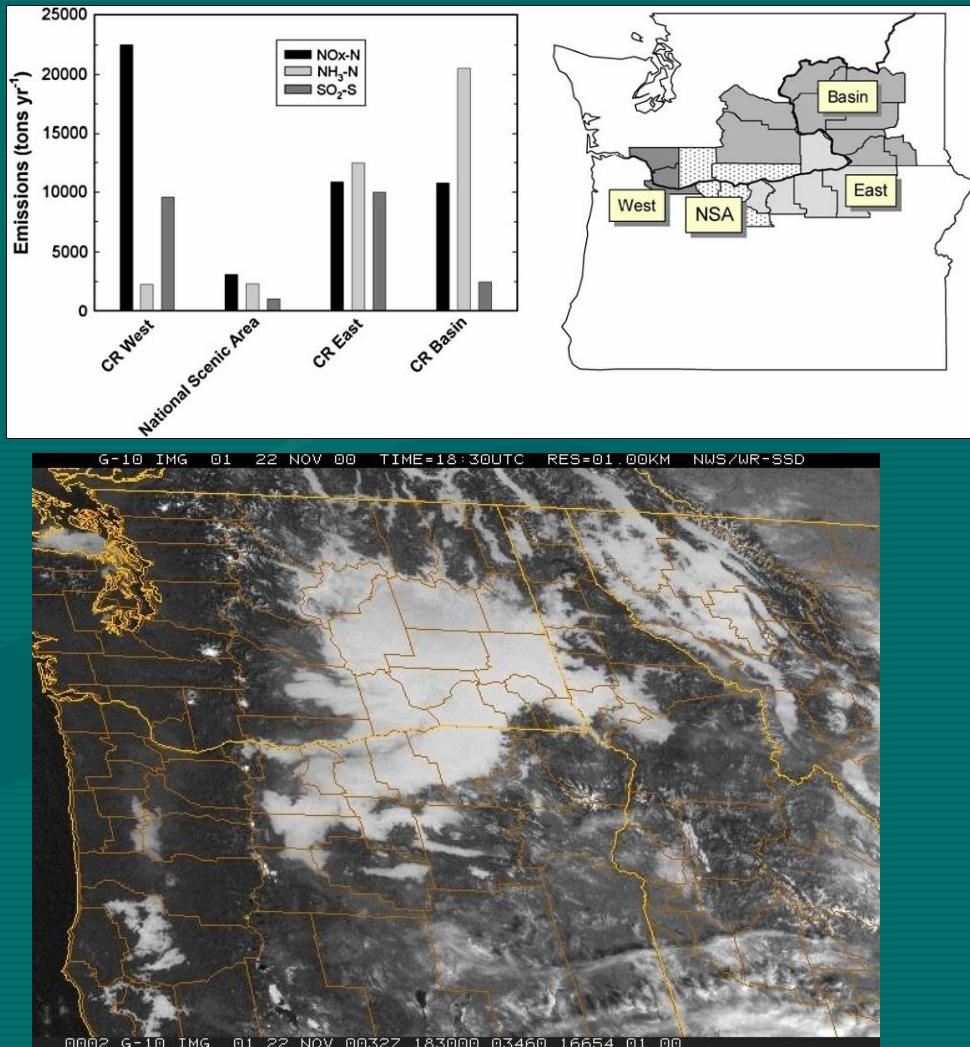
# Example 2. Columbia River Gorge National Scenic Area



- Lichen %N is higher in the CRG than surrounding National Forests
- First 10 yr re-measurements showing N increases in the CRG but not surrounding Forests
- Increase associated with eastern  $\frac{3}{4}$  not Portland vicinity.
- (not shown). S steady, Pb has decreased almost to background levels (means 5-10 ppm from 20-40 ppm)

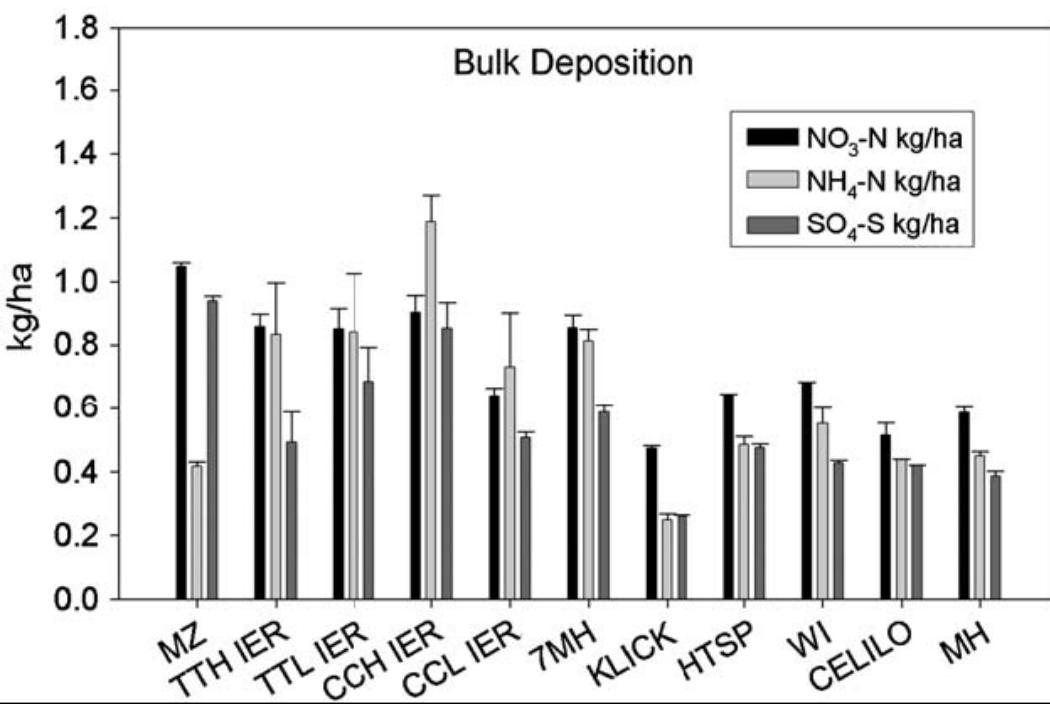
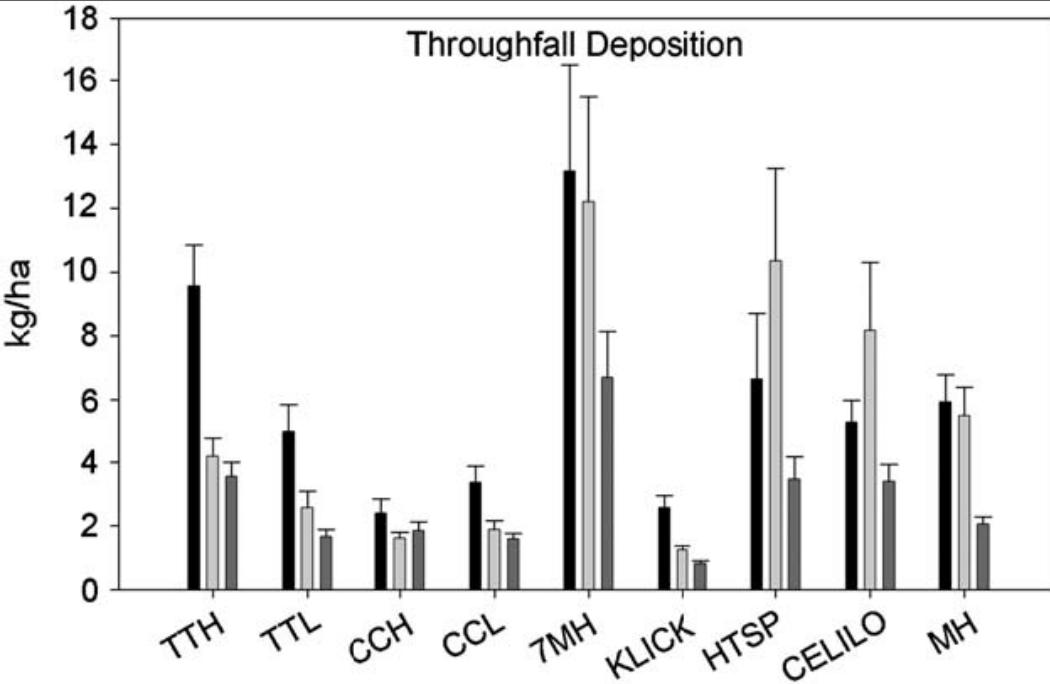
# Example 2. Columbia River Gorge National Scenic Area

- Emission inventories show that CRG contributes little pollution, most comes from Portland and Columbia Basin
- Meteorology shows air pollution from agricultural & industrial sources is trapped by winter inversions in the Basin, drains by gravity through the Gorge.
- Portland emissions are funneled through the CRG by diurnal winds, highest in summer.
- Cal-puff modelling show Boardman coal-fired power plant alone degrades visibility in the CRG on average 16-17 days/yr.



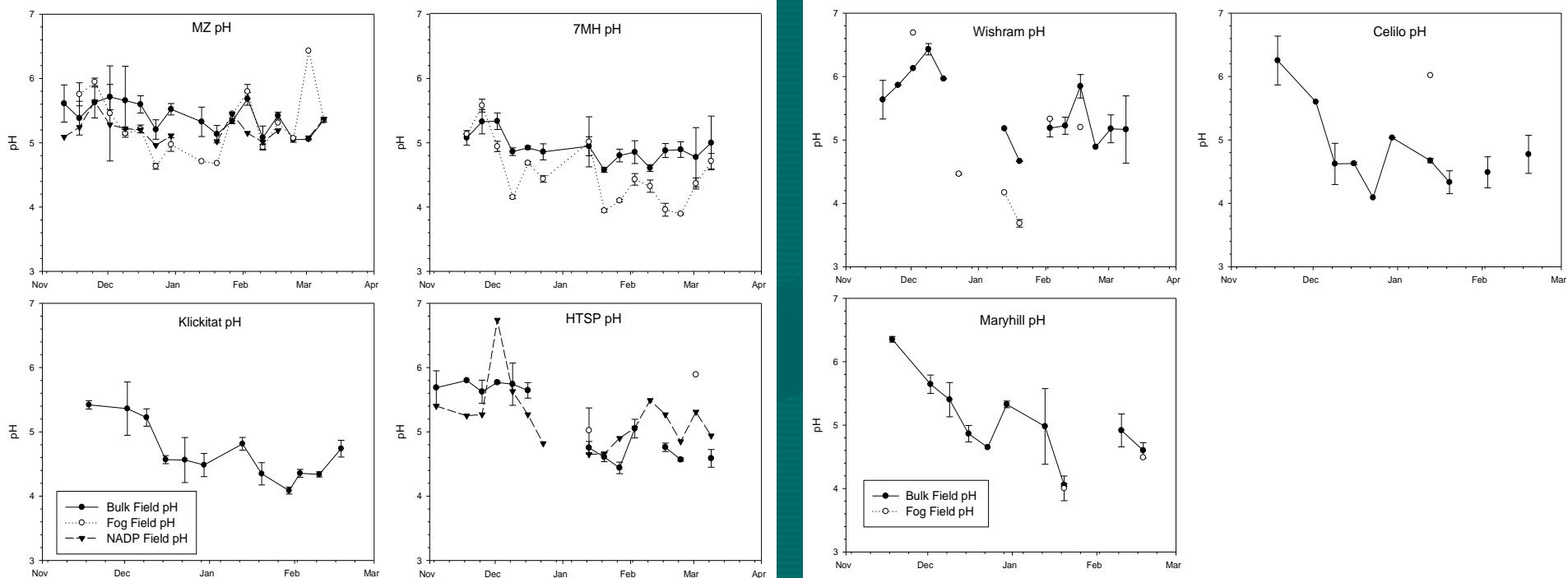
## Example 2. Columbia River Gorge National Scenic Area

- Throughfall deposition showed excessive N dep, mainly in winter
- NADP style bulk deposition underestimates actual wet deposition in forested sites



# Example 2. Columbia River Gorge National Scenic Area

- Fog water and bulk precipitation show episodes under pH 4, especially at easternmost sites



## **Example 2. Columbia River Gorge National Scenic Area**

- Forest Service studies, testimony and reports have contributed to:
  - Gorge Commission decision to overrule Economic Development Commission attempt to weaken air-quality related clauses in CRG management plan.
  - Creation of a bistate committee to ameliorate pollution in the Gorge.
  - 17 feature length articles in the Oregonian about air quality in the Gorge, numerous letters to the editor, local news reports.
  - Numerous public meetings.
  - Under pressure from the public, environmental groups, and state regulators, a commitment by the Boardman coal-fired power plant to voluntarily undergo retrofitting for best available control technology within the next 5 years.

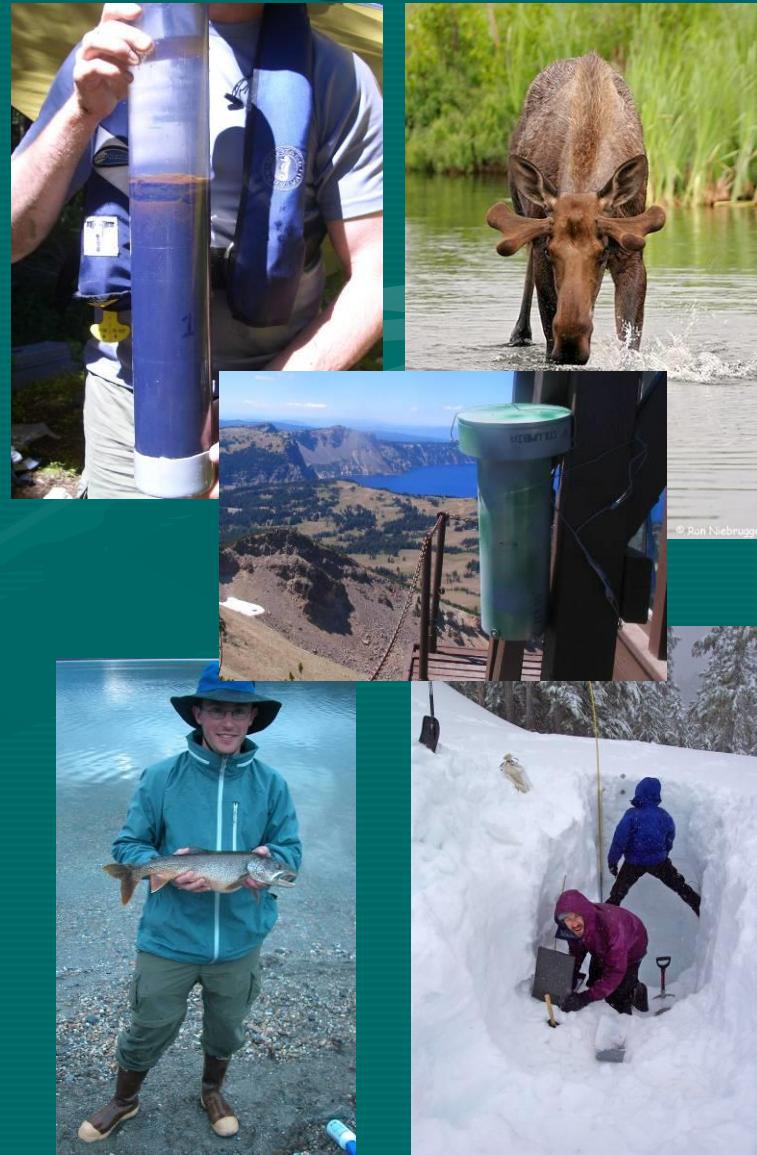
# Example 3. The Western Airborne Contaminants Assessment Program



- Objectives are to find out:
  - 1) whether persistent organic pollutants and toxic metals are accumulating in Park & Wilderness ecosystems and,
  - 2) if so, where they are accumulating (geospatially and physically within ecosystems),
  - 3) where they come from
  - 4) whether they are having adverse ecological impacts. See NPS air toxics website (*list url*)

# Example 3. The Western Airborne Contaminants Assessment Program

- Measures ~150 semi-volatile organic compounds
  - Current and banned agricultural chemicals
  - Industrial chemicals and combustion biproducts
  - Flame retardants
- 50 elements, including Hg
- Matrices: snow, lake water, lake sediments, fish, **lichens**, conifer needles, moose, passive samplers
- 19 Parks, 1 Wilderness (2-5 sites, 2-8 matrices/park)



# Lichens

- Epiphytic (MORA, SEKI, GLAC)

- *Alectoria sarmentosa*
- *Letharia vulpina*
- *Platismatia glauca*



- Terricolous (DENA, GAAR, NOAT)

- *Flavocetraria cucullata*
- *Masonhalea richardsonii*



- Saxicolous (ROMO)

- *Xanthoparmelia cumberlandia s. lato*

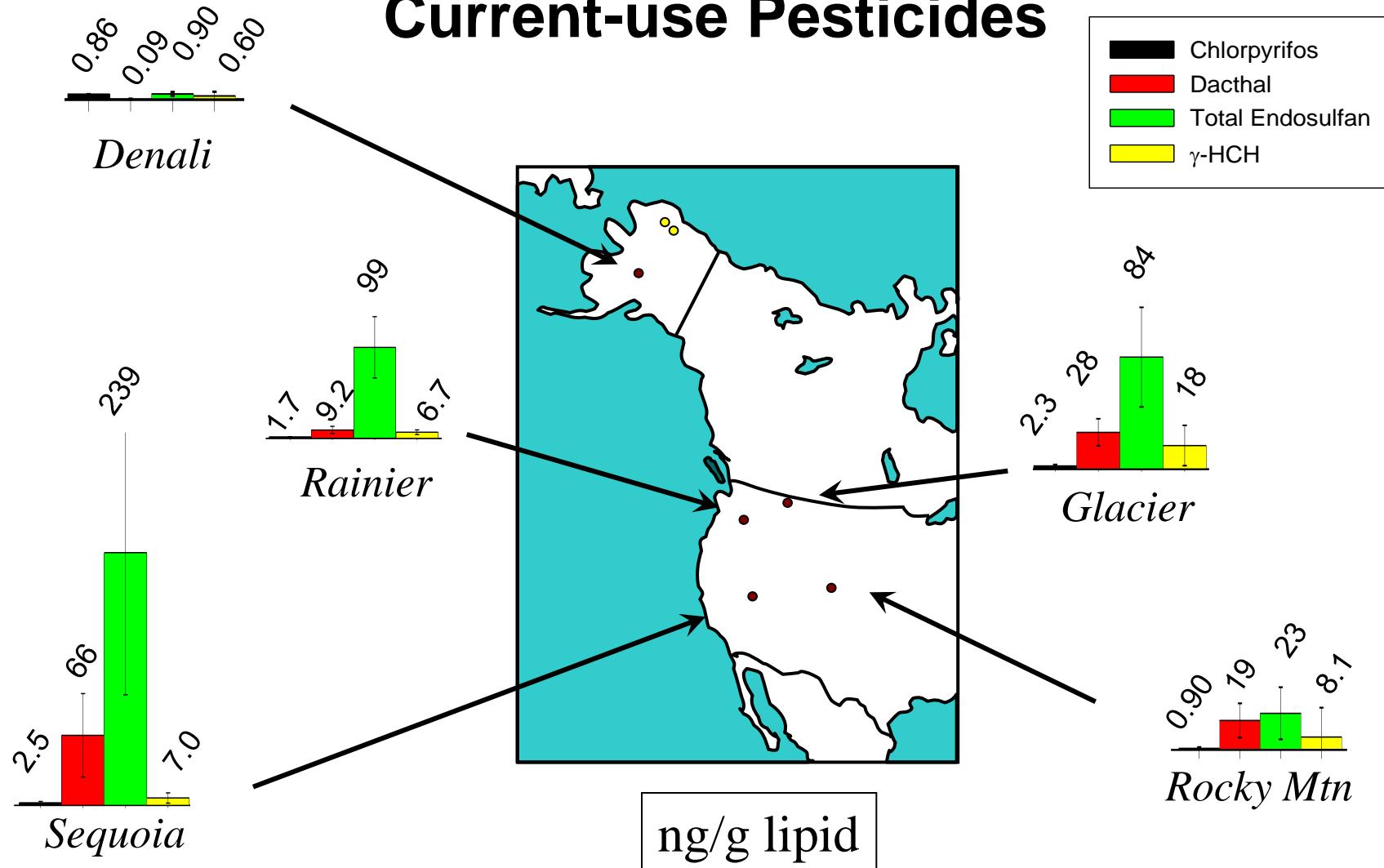


## **Example 3. The Western Airborne Contaminants Assessment Program**

- Lichens accumulate higher quantities and more compounds occur at detectable levels than conifer needles or willow bark. New instrumentation makes analysis much easier than in the past. Still expensive (\$1K/sample)
- First round of analyses have been completed for agricultural chemicals in 8 parks, all matrices.

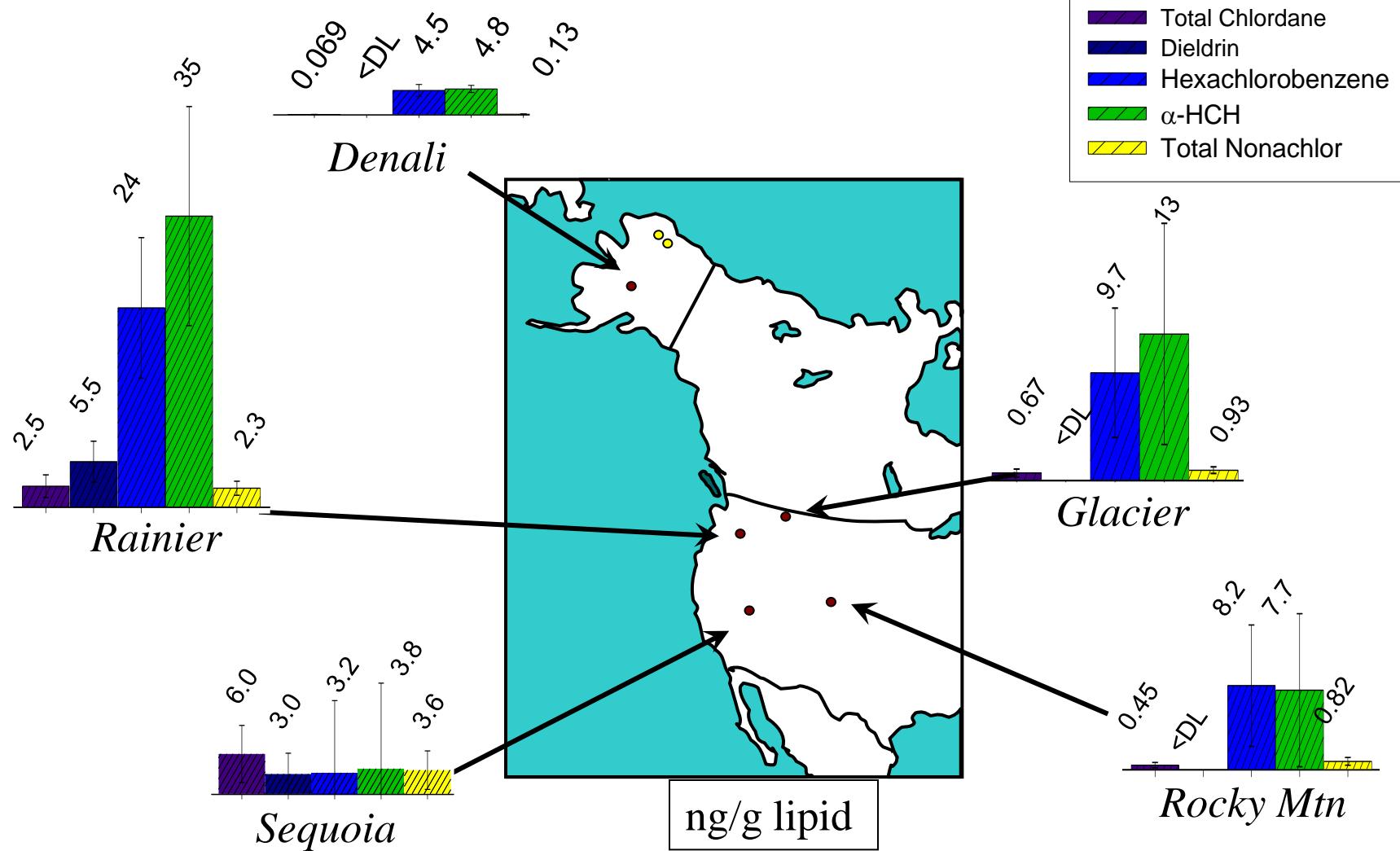
# Example 3. The Western Airborne Contaminants Assessment Program

## Current-use Pesticides

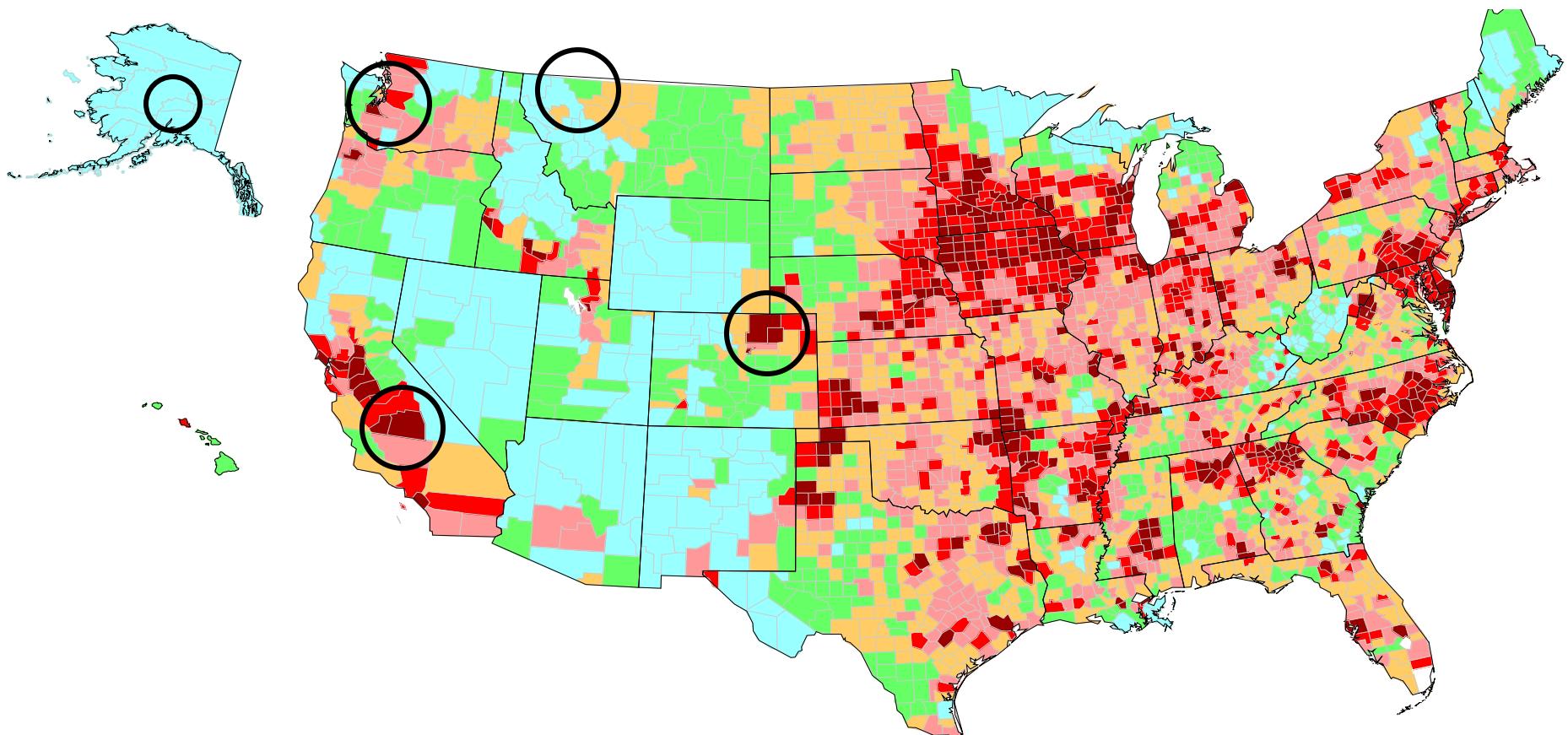


# Example 3. The Western Airborne Contaminants Assessment Program

## Historic-use Pesticides



# Example 3. The Western Airborne Contaminants Assessment Program



2001 County Emissions Density (Tons per sq.mi.) of Ammonia



0



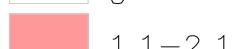
>0-0.18



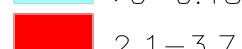
0.18-0.46



0.46-1.1



1.1-2.1



2.1-3.7



3.7+

# Example 3. The Western Airborne Contaminants Assessment Program

Table 1: R<sup>2</sup> values for correlations of concentration versus NH<sub>3</sub> emission density and Cropland Intensity

	NH3 emission density	Cropland Intensity
Dacthal	0.47*	0.31*
Endosulfan Sulfate	0.34*	0.14*
$\gamma$ -HCH	0.003	0.12*
trans Chlordane	0.51*	0.09*
HCB	0.04	0.01
$\alpha$ -HCH	0.01	0.02

\*: correlation has a p-value < 0.05

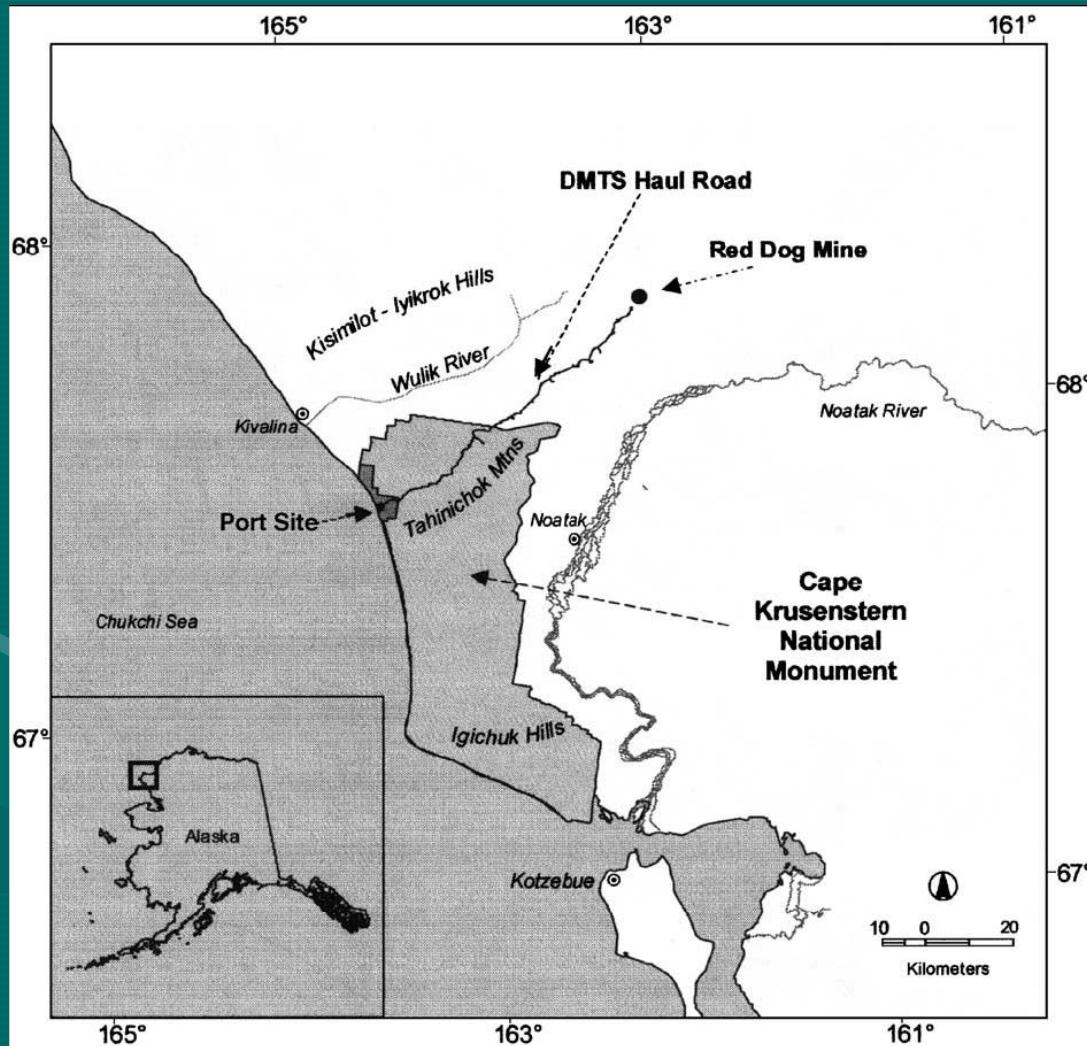
# Example 3. The Western Airborne Contaminants Assessment Program

- Snow data also showed a positive correlation between agricultural SOC concentrations and nearby cropland intensity
- Fish data
  - Macrophage aggregates in fish spleens were strongly correlated with Hg and PCB concentrations in fish tissue; Sequoia NP highest
  - Vitigellin in male fish indicates an endocrine response to environmental estrogens. Vitigellin was detected and associated with EEs at ROMO.
  - Intersex also demonstrates endocrine disruption. The intersex fish from ROMO had 2X the pp'-DDT (known estrogen) and 10-100X the dieldrin (known breast cancer and developmental effects) of the fish analyzed so far.

## **Example 3. The Western Airborne Contaminants Assessment Program**

- Many more results to come. Final report summer 2007.
- NPS will publicize report results widely via its website and the media
- If action is needed, NPS will use the report and resultant scientific articles as evidence of their concerns and prioritize areas and pollutants.
- Most probable avenue is to work with state and federal regulators.

# Example 4. Cape Krusenstern National Monument



Haul road for the transport of lead and zinc ore from Red Dog Mine through Cape Krusenstern National Monument to the Bering Ocean was authorized in 1988 by a special exemption from Congress.

# Example 4. Cape Krusenstern National Monument



The ore, 85% Zn & Pb, is powdered, separated, then trucked through the Park to the Port Site. The outside of the trucks are covered with dust, which blows onto surrounding vegetation during transport.

# Example 4. Cape Krusenstern National Monument

L. Hasselbach et al. / Science of the Total Environment 348 (2005) 211–230

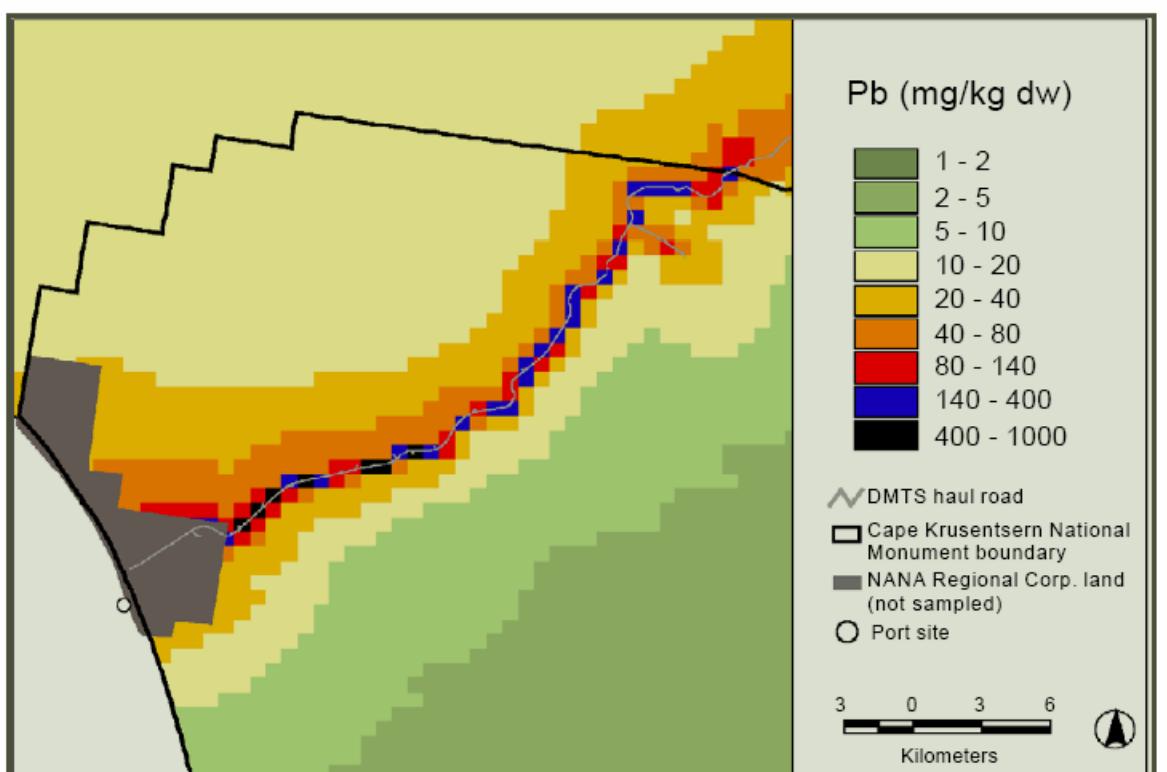


Fig. 6. Conditional simulation predictions for Pb moss concentrations along the DMTS haul road corridor.

NPS ecologists Linda Hasselbach and Peter Neitlich used the moss, *Hylacomium splendens* to spatially delineate dust impacted area. Up to 10,000 ppm in the moss at 10 m from road, decreases gradually on either side of haul road.

## Example 4. Cape Krusenstern National Monument

Results created political uproar, widespread media attention, tough scientific scrutiny of the report, head-hunting, and a major law suit on behalf of the park by the Trustees for Alaska. Resulted in:

- Replacement of truck fleet with covered vehicles
- Enclosure of the conveyor belt between storage sheds and port site
- Sealing of concentrate storage buildings and addition of reverse air flow to reduce leakage of dust

# Example 4. Cape Krusenstern National Monument

Currently working to define the correlation between moss content and species richness of lichens, bryophytes and vascular plants, and metal levels in birds and small mammals.



National Park Service botanists evaluate lead & zinc contaminated road dust effection on lichen, byrophyte and vascular plant diversity in Cape Krusenstern N.M., arctic Alaska.

## Example 4. Cape Krusenstern National Monument

- The new work will be used as an independent verification of the risk assessment study submitted to the ADEC by industry-funded Cominco.
- Depending upon results will result in mitigation or creation of an action plan between the mine and the NPS.
- Possible further actions could include:
  - Indoor truck washing and better road dust control

# Start to finish steps

All steps need to be completed to effect change:

- *Preparation:* design, funding, buy equipment, hire personnel
- *Data collection*
- *Data analysis*
- *Data reporting:* internal reports (fast, easy to use), peer-reviewed (needed for long term credibility)
- *Public awareness:* newspaper reports, public debate, public meetings, NGO—elected public officials are most responsive to the public
- *Negotiation:* NSR, meetings with state or federal regulators, industry, NGOs, tribes, other stake holders.
- Pollution abatement and prevention: the hoped for result

# Summary of Lichen Data Uses

Lichen community composition and thallus chemistry can be used effectively to/for:

- Inexpensive explorative sampling.
- Geographically delineate the area of concern
- Detect trends : spatial and temporal
- Provide evidence of adverse ecological effects
- Provide evidence of enhanced accumulation of pollutants in vegetation
- Look for ecological responses to fertilizing, acidic, and oxidizing pollutants, and toxic metals.
- Indicate relative deposition of sulfur, nitrogen, metals, other elements, and semi-volatile organic compounds
- Educate
- Protect and improve air quality

# Acknowledgements

- *USFS Air Program*: Bob Bachman, Jim Russell, Mark Boyll, Anne Ingersoll, Jim Riley, Doug Glavich, Adrienne Marler, John Szymoniak, Alexander Mikulin, Karen Dillman, Jill Grenon, Larissa Laselle, Rich Fisher, Earl Baumgarten, Jerry Hustafa, Steve Ellis, Rachael Bennet, Molly Lowe, Judy Redner, Mark Kreiter
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- *CIRUS*: Scott Copeland
- *University of Minnesota-St. Paul Research Analytical Laboratory*: Roger Eliason, Star Hormann